DETECTOR RESPONSE MODELING

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1.0 INTRODUCTION

The purpose of this paper is to present information regarding current fire detector response modeling. Fire detector response modeling in this paper refers to heat detectors, including sprinkler links. While smoke detectors can be modeled using current heat detection models, this is not highly recommended due to the magnitude of the uncertainties associated with the predictions.

It is hoped that this brief paper will provide sufficient information regarding heat detector modeling such that decisions can made regarding their applicability in nuclear power plants (NPP). If it is decided that the current model is insufficient for such applications, then this paper should provide enough information upon which to base a decision regarding future work.

2.0 DISCUSSION

2.1 Detector Modeling

The overall [smoke] detection process has been organized into five categories; property generation, bulk property transport, local property transport, sensor modulation, and alarm condition. [6] The first three categories are required by all detection models: the fire generates the hazard to be detected; the plume transports the hazard conditions to the ceiling; the ceiling jet transports the hazard condition to the point in space of interest. The final two categories are detector specific: "sensor modulation" can be thought of as modeling how the sensor "knows" what conditions are present; "alarm condition" is essentially the set point of the detector. In the case of a sprinkler or heat detector, sensor modulation models the heat transfer to the sensing device and the alarm condition is either a temperature (range) or a rate of temperature rise.

2.2 DETACT-QS

Currently, DETACT-QS is the only heat detector model that is publicly available. Other fire models may also be used to predict detector activation; however, this is not necessarily their only purpose.

2.2.1 Intent

DETACT was developed to calculate the response time of ceiling mounted heat detectors/sprinklers and smoke detectors, installed under large unobstructed ceilings, for fires with user defined, time dependent heat release rate curves [1]. DETACT is based on quasi-steady ceiling jet assumptions [2,3]. The thermally activated device must be located under the ceiling and within the ceiling jet.

2.2.2 Assumptions and Limitations

1) The detector is ceiling mounted and located at the points of maximum temperature and velocity within the ceiling jet below a ceiling [2]. The detector must be within 6% of the ceiling height from the ceiling [4].

2) The ceiling is unconfined, unobstructed, smooth, flat, and horizontal. The model does not account for hot gas layer effects due to walls or obstructions. The minimum wall to wall distance is 2 to 4 ceiling heights. Vertical obstructions are required to be less than 1% of the ceiling height for the ceiling to be considered smooth [2].

3) Only convective heat transfer is considered between the ceiling jet and the thermal detector; no conductive or radiative heat transfer is considered. The detector is treated as a lumped mass model [5]. The lumped mass model assumes that the thermal gradients are neglected within the thermal element.

4) Smoke detector activation is assumed at a ceiling temperature increase of 13°C [1]. (Although this is a gross over-simplification of the phenomenon, it is an all too commonly used assumption.)

5) Within the plume impingement area, temperature ($r/H \leq 0.18$: r = radial distance between plume centerline and detector; H = height of ceiling above the fuel) and velocities ($r/H \leq 0.15$) are uniform an assumed to be the maximum values in the plume [2].

6) The fuel package and the plume are assumed to be in an unobstructed vertical axis. No ventilation or stratification effects are considered. The heat release rate or the fire needs to be sufficiently large so that the plume can be assumed to be vertical and axisymmetric [2].

7) No transport time (or lag time) is considered for the hot gases to travel from the fuel to the detector [2]. Therefore, increases in heat release rate will effect the temperature and velocity of the ceiling jet immediately.

8) For each heat release rate input interval, the heat release rate is averaged over the interval and assumed constant. Fire heat release rate should not double in less than one minute [2].

9) Detector must be spot type [4].

2.3 SFPE Computer Model Evaluation Task Group Report

2.3.1 Intent

The draft report of the SFPE task group [4] states as its purpose: "This evaluation report provides information on the technical features, theoretical basis, assumptions, limitations, sensitivities and guidance on the use of DETACT. This evaluation is based on comparing predictions from DETACT with results from full-scale fire experiments conducted in compartments with ceiling heights ranging from 2.44 m to 12.2 m and peak fire heat release rates ranging from 150 kW to 10MW."

The type of evaluation that DETACT was subjected to is classified in ASTM E-1355 [7] as a "specified calculation." In the specified calculation, the model user is provided with a complete detailed description of model inputs, including geometry, test conditions, and the heat release rate history of the fire [7].

2.3.2 Conclusions

Actuation temperature is the most sensitive input parameter; i.e., for a given percentage change in the value of actuation temperature used by DETACT, it predicted a larger percentage change in the output parameter(s) of interest.

When slow t-squared fires are used, the predicted actuation time will greatly increase due to the relatively slow development of the fire. Very small source fires, especially smoldering, fall outside the bounds of the analysis and are unlikely to be accurately predicted, either for ceiling jet temperatures or detector actuation, by DETACT [4].

"Based on the comparison to predictions with measured values:

- As the ceiling height increased from 3.0 m to 12.2 m, the agreement between the predictions and the data improved. The lower ceiling heights are more sensitive to uncertainties in the experiment.
- There was better agreement between devices with higher RTIs (response time index) than with devices with lower RTIs.
- The compartment evaluation scenarios demonstrate that DETACT should not be used in situations where the limitations/assumptions of the model cannot be met, since the model cannot be used with any reasonable expectation of reliability. For example, the use of DETACT would not be appropriate in small areas where a gas layer would develop prior to activation." [4]

2.4 Proposed Tasks

2.4.1 Scenarios to be Modeled

The first task is to define those scenarios requiring the prediction of fire detector activation. The scenario definition should include a geometrical description of the room of fire origin (turbine hall, control room, etc.) and specify the fire that may be experienced in that space. Presumably, the type of heat detector and its description is a "given" for each NPP.

2.4.2 Scenario Differences

The scenarios described in 2.4.1 are next compared to the limitations presented in 2.2.2. Any inconsistencies are to be noted for the following step.

2.4.3 Questions

The series of questions below (in no particular order) is intended to facilitate the discussion:

1) Do the limitations shown in 2.2.2 preclude using DETACT in NPP?

2) Are the identified NPP scenarios sufficiently similar to those used in the development of DETACT (see 2.2.2) to justify further work?

3) If they are not sufficiently similar is it still worthwhile to investigate using DETACT in NPP scenarios? For example, since there is no other detector model available, are we "forced" to use it?

4) Is there a "best" way to use DETACT in NPP? Some of the choices for "best" include:
    - as is (i.e., no changes)
    - modify program based on available data
    - develop post-processor adjustment factors (may require using CFD models to generate ceiling jet temperature and velocity profiles and develop correlations based on the results)
    - develop a new DETACT for NPP (i.e., extract property generation, bulk property transport, and lumped mass models from DETACT and couple those to NPP-specific ceiling jet temperature and velocity correlations)

5) Is ceiling jet temperature and velocity experimental data available for the scenarios of interest?

2.4.4 Benchmark Exercise

If there is sufficient interest in pursuing detection modeling in NPP the questions posed in 2.4.3 must be addressed first. Assuming that the decision is to proceed, some sort of benchmark exercise will be needed. In order to undertake such an exercise experimental data sets depicting the scenarios of interest must be readily available. The number of data sets needed will depend on the nature of the exercise.

The nature of the exercise will depend on the answer to Question 4 of 2.4.3. If the decision is made to compare DETACT prediction to experimental data and develop post-processor adjustment factors, then a relatively small number of data sets is required (probably three to four). If the decision is made to use the DETACT lumped mass model as the "sensor modulation" and "alarm condition", and the "property generation" and "bulk property transport" portions of DETACT along with a NPP specific ceiling jet correlation, then more data sets will be required: at least six. The idea here is that three data sets could be used to develop the NPP specific ceiling jet correlations, and the other three could be used to benchmark the resulting model.

It may be advantageous to use ASTM 1355 [7] as guidelines for this benchmarking exercise. Several types of model evaluations are presented: blind calculation (basic description of scenario provided); specified calculation (detailed description of model inputs provided); and open calculation (most complete information provided, including experimental or other benchmarking data). Using ASTM 1355 would provide some structure and formality to the exercise.

3.0 SUMMARY

The limitations imposed on the use of DETACT will most likely preclude its widespread use in NPP. However, assuming that there is a need for detector modeling in NPP, the question then becomes one of deciding what is the best (most expedient, most defensible...) course to meet this need.

Presumably, four of the five components necessary for NPP detector modeling are present in the current version of DETACT-QS. The DETACT component which needs either replacement or augmenting is that describing "local property transport." In order to address NPP specific local property transport, post-processing adjustment factors or a new component must be developed for DETACT.

4.0 REFERENCES

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2) Alpert, R.L., "Calculation of Response Time of Ceiling -Mounted Fire Detectors," *Fire Technology*, **9**, 1972.

3) Alpert, R.L., "Turbulent Ceiling-Jet Induced by Large-Scale Fires," *Combustion Science and Technology*, **11**, 1975, pp. 197-213.

4) *Evaluation of the Computer Fire Model DETACT-QS*, August 2000 draft report, Society of Fire Protection Engineers, Bethesda, MD, 2000.

5) Heskestad, G. and Smith, F.H., *Investigation of a New Sprinkler Sensitivity Approval Test: The Plunge Test*, FMRC 22485, Factory Mutual Research Corp., Norwood , MA, December, 1976.

6) Ierardi, J.A. and Barnett, J.R., "A Methodology for Predicting Smoke Detector Response", *Proceedings 4th International Conference on Performance-Based Codes and Fire Safety Design Methods*, Society of Fire Protection Engineers, Bethesda, MD, 2002.

7) *ASTM E1355-97 Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models*, American Society for Testing and Materials, 1997.

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Purpose

- Background
- Proposal

Background

- SFPE Computer Model Evaluation Task Group
  - First model DETACT
    - 3+ year effort
    - Report issued soon
  - Next model ASET
    - (shouldn't take 3 years...)

DETACT evaluation

- ASTM E-1355: many tasks
  - Verification of algorithm
  - Sensitivity analysis
  - "Blind" runs
- Attempted to compare algorithm to original data
- New tests conducted
  - Problems eventually worked out

DETACT

- Predicts activation time of fixed-temperature detectors
  - Not for rate-of-rise
  - Smoke detectors...

- Correlations for
  - Ceiling jet temperature
  - Ceiling jet velocity

DETACT Limitations

- Large, flat, smooth ceiling
- Unconfined, minimal layer formation
- Detector assumed to be exposed to max CJ velocity and temperature
- Implicit accounting of radiation and conduction

Proposal

- Nuclear installations not
  - Smooth
  - Flat
  - Open
- Does DETACT still apply?
  - What happens when DETACT is used?

Proposal

- Is an evaluation of DETACT for nuclear power plant applications a good thing to do?
  - Focus too narrow?
- Is it possible to develop a "post-prediction" correction factor to account for nuclear configurations?
  - "Implicit" accounting of non-ideal configurations

Discussion

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